

## Planetary Ring Studies

Jeffrey N. Cuzzi (Ames Research Center),  
 Anthony R. Dobrovolskis (U. C. Santa Cruz), Luke Dones (C. I. T. A.),  
 Richard H. Durisen (Indiana), Linda Horn (J. P. L.), Mark R. Showalter (Stanford)

This research contains a large number of tasks, representing the efforts of the coinvestigators listed above. Limited space allows only the briefest highlights to be noted.

**Characterization of the fine scale structure in Saturn's A and B rings**

We have obtained the highest available resolution full scan of Saturn's B and inner A rings from about a dozen narrow angle camera images (Voyager 2 data, illuminated face, resolution about 3.5 km/pixel). This data was then analysed for its spatial frequency content using a Burg maximum entropy algorithm (Horn et al. 1990) and also using a standard FFT algorithm. We checked the ability of both the FFT and Burg algorithms to return detections of less than fully periodic simulated data in the presence of noise. The purposes of this check were to validate the Burg technique, and to assure ourselves that it was not producing spurious results.

The structure we are finding in the B and A rings does have characteristic scales which presumably contain clues as to its origin. The characteristic scale varies somewhat across the inner B ring but is all within the range of about 70-90 km. There is no significant spectral power on either shorter or longer scales, a conclusion which is validated by inspection of the images themselves. Beginning in the vicinity of the Janus 2:1 density wave at 96200 - 96500 km, the structural scale increases to 200 - 300 km, and this larger scale then dominates throughout the rest of the B ring. The central third or so of the B ring is practically devoid of structure on scales finer than about 200 km, but fine scale structure reappears in the outermost few thousand km of the B ring *superposed* on the 200 - 300 km scale structure.

**Ballistic transport modeling and evolution of fine ring structure**

We have improved our numerical scheme for computing the evolution of planetary rings due to ballistic transport (Durisen et al. 1989). We are now routinely able to compute evolutions over many tens of "gross erosion times"  $t_g$ , where  $t_g = \sigma / \dot{\sigma}_{ej}$ , with  $\sigma$  the ring surface mass density and  $\dot{\sigma}_{ej}$  the rate of ejecta loss due to direct bombardment. Typically,  $t_g \sim 1.5 \times 10^5 (10^5/Y)$  years where  $Y$  is the ejecta mass yield per unit mass projectile ( $\sim 10^4 - 10^6$ ).

The detailed, strongly prograde *angular* ejecta distribution for nondisruptive impacts, computed by Cuzzi and Durisen (1990), has been incorporated. Along with this, two realistic ejecta *velocity* distributions  $f(>v)$  are currently utilized in our code, where  $f$  is the ejecta fraction with ejection velocity magnitude  $> v$  between 4 and 80 m/s. One has a "knee" at 10 m/s and another is a pure  $v^{-2}$  powerlaw. The code computes viscous spreading using various current models of viscosity which are normalized to an upper limit of  $0.05 \text{ cm}^2/\text{s}$  for the C ring.

The inner edges of Saturn's A and B-rings have similar morphology but do not correspond to known external resonances or to resonances with oscillatory modes of Saturn, and are thus prime candidates for displaying effects of ballistic transport. Durisen et al. (1990,1991) demonstrate that, for a plausible range of  $f$  and  $Y$ , a steady-state edge about as sharp as observed can be produced in a few  $t_g$  and can thereafter be maintained *despite viscosity*. As long as  $Y$  is large enough for ballistic transport to dominate viscosity, we also find a "ramp" to be a robust feature in our inner edge simulations. We have used an analytic approximation show that a ramp near a high- $\tau$  edge is an inescapable consequence of ballistic transport for a power-law

$f$  combined with a strongly prograde distribution of ejecta velocities. In fact, for a realistic  $f \propto v^{-2}$ , the ramp is precisely linear in  $\tau(r)$ , as is the case for the observed ramps.

Durisen et al. (1990,1991) also demonstrate how the typical ejecta velocities determine the typical length scales. For high  $Y$  and the power-law  $f$ , the edge is sharper and the undulatory structure has characteristic radial width of about 150 to 200 km (Horn and Cuzzi 1990).

### **Faint features in the rings of Saturn**

By combining a variety of Voyager and Earth-based data, Showalter et al. (1991) have shown that the E Ring is composed of a very narrow distribution of particle sizes centered around 1 micron, which makes the E Ring unlike any other known planetary ring. This result rules out the possibility that the E Ring particles originate in collisional or disruptive processes, and therefore gives credibility to several prior theories that the particles originate in volcanic or geyser-like phenomena on Enceladus. These ideas are not implausible in light of the recent discovery of geyser-like plumes on Triton.

In a search for azimuthal periodicities in the F Ring images, Kolvoord et al. (1990) found the signature of Prometheus but not that of the more distant and less massive Pandora. In addition, potential signatures of several unidentified objects, possibly members of an F ring moonlet belt (Cuzzi and Burns 1988), were observed.

### **The Encke Moonlet Revealed**

One of our research highlights in the last year was the visual detection of Saturn's eighteenth moon, now designated 1981S13. The body orbits within the Encke Gap of the A Ring. The presence of this moonlet was originally inferred indirectly in research supported under this RTOP. This year, Showalter used our solution for the moonlet's orbit to perform a computer search of the Voyager image collection which identified every frame whose field of view was expected to contain the moonlet. He has since located 1981S13 in 23 Voyager 2 images, and used its location to infer a precise orbit for the body (Showalter 1990, 1991).

### **Dynamics in ringmoon systems:**

We are studying ringmoon belts with potential application to the F ring region, the Encke gap region, and the Uranian and Neptunian ringmoon systems in general. Our focus at present is on the steady state dynamics of a population of moonlets as perturbed by one or two nearby ringmoons. We had hoped to study the dynamical forcing aspects of this situation using a mapping approach (e.g. Duncan et al 1989). However, we noticed that the map-predicted onset of chaotic behavior was sensitive to the precision of the computer arithmetic and even the platform (Vax or Cray). We decided to check the map results with a Bulirsch-Stoer integration, which implied that the map often does predict chaos which is artificial.

We attempted to improve the mapping by introducing orbit curvature terms to correct for the less-than-fully-applicable Hill approximation which provided the basis for the map of Duncan et al (1989), and by trying to derive a symplectic or Hamiltonian-based mapping scheme which would be area preserving. So far, we have found no suitable way to treat this particular problem with confidence from a mapping standpoint. However, the Bulirsch-Stoer integration scheme is actually quite fast as well as thoroughly reliable, and we have decided to rely on it for the present.

### **Non-classical radiative transfer model**

We have continued development of our "ray-tracing" light scattering code for modeling

realistic planetary rings (Dones et al. 1989). In the last year we have found a better way to treat multiple scattering. Both the old and new codes use a successive-orders-of-scattering approach. However, in the old version, each scattering event from a particle yielded only a single "daughter" ray, whose direction was selected in a rather complicated way. In the new code, each scattering except the final one to the observer results in several daughter rays, with directions uniformly distributed in solid angle in the outgoing hemisphere. The phase function of the particle is incorporated by assigning different weights to the rays.

### **Particle Properties from Stellar Occultation Data**

Our derivation of the relationship between Voyager PPS photon counting statistics and Saturn ring particle sizes was published recently (Showalter and Nicholson 1990). The particle sizes derived in the C Ring and Cassini Division are generally compatible (within a factor of 1.5 - 2) with previous determinations using Voyager Radio Science data, but our technique provides a sense of particle size variation on radial scales much smaller than by any other means.

### **References**

- Cuzzi, J. N. and J. A. Burns (1988) Charged Particle Depletion Surrounding Saturn's F Ring: Evidence for a Moonlet Belt; *Icarus*, 74, 284-324
- Cuzzi, J.N., and Durisen, R.H. (1990), Bombardment of Planetary Rings by Meteoroids: General Formulation and Effects of Oort Cloud Projectiles, *Icarus*, 84, 467 - 501
- Dones, L., Showalter, M., and Cuzzi, J. N. (1989). Simulations of Light Scattering in Planetary Rings. In "Dynamics of Astrophysical Discs"; Cambridge University Press.
- Duncan, M., T. Quinn, and S. Tremaine (1989) The long-term evolution of orbits in the solar system: a mapping approach; *Icarus*, 82, 402-418
- Durisen, R.H., Bode, P.W., Cederbloom, S.E., Murphy, B.W., and Cuzzi, J.N. (1990), Theoretical Models for the Structures at Saturn's A and B-Ring Inner Edges, *Bull. Am. Astron. Soc.*, 22, 1045 (abstract: poster paper).
- Durisen, R.H., N.L. Cramer, B.W. Murphy, J.N. Cuzzi, T.L. Millikin, and S.E. Cederbloom. (1989). Ballistic Transport in Planetary Ring Systems due to Particle Erosion Mechanisms. *Icarus*, 80, 136-166.
- Durisen, R.H., Bode, P.W., Cuzzi, J.N., Cederbloom, S.E., and Murphy, B.W. (1991), Ballistic Transport in Planetary Ring Systems due to Particle Erosion Mechanisms. II. Theoretical Models for Saturn's A and B-Ring Inner Edges, *Icarus*, in preparation.
- Horn, L.J., and Cuzzi, J.N. (1990), Spatial Scales in Saturn's B-Ring, *Bull. Am. Astron. Soc.*, 22, 1041
- Kolvoord, R. A., J. A. Burns, and M. R. Showalter 1990. Periodic features in Saturn's F Ring: Evidence for nearby moonlets. *Nature* 345, 695-697.
- Showalter, M. R. 1990. The visual detection of 1981S13, the Encke Gap moonlet. *Bull. Amer. Astron. Soc.* 22, 1040-1041.
- Showalter, M. R. 1991. The visual detection of 1981S13 and its role in the Encke Gap. Submitted to *Nature*.
- Showalter, M. R., J. N. Cuzzi, and S. M. Larson 1991. Structure and particle properties of Saturn's E Ring. Submitted to *Icarus*.
- Showalter, M. R., and P. D. Nicholson 1990. Saturn's rings through a microscope: Particle size constraints from the Voyager PPS scan. *Icarus* 87, 285-306.